14.4 Habitat Valuation Analysis (HGM)

1.0 Ecosystem Restoration Evaluation Methodologies

1.1 Species-Based Habitat Indices

USACE presently uses the habitat unit concept to characterize the non-monetary outputs of ecosystems that must justify project costs. The concept is closely associated with development of the Habitat Evaluation Procedures (HEP) developed under the lead of the U.S. Fish and Wildlife Services (USFWS 1980a-c). HEP measures the effects of environmental change through a series of species-based Habitat Suitability Indices (HSI) developed for approximately 160 individual fish and wildlife species. The species-based HSI models rely on field measured habitat parameters, which are integrated into a single, probability-of-use index ranging from 0 to 1.0. HEP uses a simple multiplication product of impacted area in acres and HSI to calculate Habitat Units (HUs).

Species-based Habitat Suitability Index (HSI) models deployed in the traditional Habitat Evaluation Procedures (HEP) methodology are numerous, easy to use, are relatively inexpensive, but not immediately available or applicable to the arid southwest region, and do not capture all of the important habitat/ecosystem elements or all of the justifying value needed to restore ecosystems. Species-based HSI models are not scaled based on ecosystem integrity and should only be used to indicate a more naturally integrated ecosystem condition when the HSI value is known for the targeted restored condition. Few existing single-species HSI models satisfy these criteria well, but ecosystems might be characterized by new models for native dominant and keystone species, including dominant plant species and top-carnivore species, used in series with a few HSI models for rare species in the community. Several species-based HSIs might then "bracket" the community-habitat relationships satisfactorily, but the need for many new models offsets the main existing advantage.

1.2 Community-Based Habitat Indices

Existing community- based HSI models offer more promise than species-based HSI models because they are more efficient in capturing those habitat measures necessary for restoring ecosystem integrity and can be compared across a wide range of ecosystems for prioritization purposes (Stakhiv, et al. 2001). Community-based HSI models indicate relative ecosystem value more inclusively than species-based models because they link habitat more broadly to ecosystem components or functions. While species richness is relatively easy to link to habitat features in community-based HSI models, species richness may not predict the number of endangered species present in an ecosystem very well. Most species richness measures are limited to one to a few taxonomic categories, such as birds, fish, or aquatic insects. The taxonomic groups chosen for characterizing integrity may not characterize to fine enough degree the habitat needs of the endangered species. Complete models would need to account for this potential deficiency by assuring the diversity measure is inclusive of the vulnerable species or by including a separate relationship between vulnerable-species and habitat conditions. Again, each community would require a unique model of habitat-species relationships. Relatively few community prototype models have been developed, however, and most of the models would require considerable investment to cover the variety of ecosystems managed by the Corps.

1.3 Function-Based Indices

USACE's Environmental Laboratory (Engineer Research and Development Center, Vicksburg, MS) developed a similar approach to assessing the functional capacity of a wetland using standard wetland assessment protocols typically deployed in the regulatory arena. Referred to as the HydroGeoMorphic Approach (or HGM), an assessment model is developed and serves as a simple representation of functions performed by a wetland ecosystem (Ainslie et al. 1999). The model defines the relationships between one or more characteristics or processes of the wetland ecosystem or surrounding landscape and the functional capacity of a wetland ecosystem. Functional capacity is simply the ability of a wetland to perform a function compared to the level of performance in reference standard wetlands. The HGM methodology is based on a series of predictive Functional Capacity Indices (FCIs) – quantifying the capacity of wetlands to perform a function relative to other wetlands from a regional wetland subclass in a reference domain. Functional capacity indices are by definition scaled from 0.0 to 1.0. An index of 1.0 indicates that a wetland performs a function at the highest sustainable functional capacity, the level equivalent to a wetland under reference standard conditions in a reference domain. An index of 0.0 indicates the wetland does not perform the function at a measurable level and will not recover the capacity to perform the function through natural processes. FCI models combine Variable Sub-indices VSIs in a mathematical equation to rate the functional capacity of a wetland on a scale of 0.0 (not functional) to 1.0 (optimum functionality). An HGM subclass model is basically an assimilation of several FCI models combined in a specific fashion to mimic a site's functionality. Users can review and select several FCI models to evaluate the overall site functionality. All FCI models are described using a single FCI formula (refer to the Single Formula Subclass Models section below). Some examples of HGM FCI models include floodwater detention, internal nutrient cycling, organic carbon export, removal and sequestration of elements and compounds, maintenance of characteristic plant communities, and wildlife habitat maintenance.

1.4 Process Simulation Models

Process simulation models are based (in theory) on ecosystem process and offer the greatest flexibility in use and management insight with respect to the output generated with incremental additions of restoration measures (Stakhiv, et al. 2001). Functional stability could in theory be analyzed directly. In terms of basic processes, similar principles operate across all ecosystems. However, process models rely on fundamental understanding of the way ecosystems operate and are extremely "information hungry". Much can be learned about how ecosystems work during assembly of process models, but the ultimate models for evaluating non-monetized environmental service are many years away even if research investment were substantially increased. The past objections to process models having to do with inadequate portability and computational capability are less likely to apply now. Even so, the details of resource partitioning into communities of different species richness and functional stability require much research and development. In the process of assembling such models, much more could be learned than from index models about managing ecosystem process for more reliable service delivery (sustainable development?) across all monetized and non-monetized services. Process simulation shows the most promise for incorporating tradeoff analysis within single model operations.

1.5 Selection of the HGM Method for the Arizona Studies

In 2002, the District began the process of formulating alternative designs for the five Arizona Ecosystem Restoration Planning Studies (El Rio Antiguo on the Rillito River, Paseo de las Iglesias and Tres Rios del Norte on the Santa Cruz River, Rio Salado Oeste and VaShly'ay Akimel on the Salt River). The District partnered with the U. S. Army Engineer Research and Development Center, Environmental Laboratory (EL), the U.S. Fish and Wildlife Service (USFWS), and the Arizona Game and Fish Department (AZGF) to ensure all stakeholder issues were considered.

Setting ecosystem restoration objectives and performance criteria on the holistic recovery of "non-use" benefits, such as wildlife habitat, hydrology and biogeochemical processes, was critical to the overall planning process for the studies. It is important to note that the basic ecological premise behind ecosystem restoration is the recovery of limiting components, defined by their primary functional characteristics, be they water, soils and/or habitat structure. The primary goal of the studies was therefore focused on the restoration of such functional components within the Study Area. To measure the success of the ecosystem restoration proposals, the best available science was brought to bear. In most ecosystem restoration studies, benefits are measured using quantifiable techniques rather than qualitative assessments. It was important then, that the technique selected to quantify benefits for the studies be repeatable, efficient and effective, as results could be questioned by outside interests. Many rapid assessment techniques were readily available to the Evaluation Teams in off-the-shelf formats in 2002, but for the various reasons described in the next section, HGM was selected (HydroGeoMorphic Assessment of Wetlands) to quantify the anticipated benefits gained by the proposed ecosystem restoration activities.

Again, HGM emphasizes the functions associated with the range of physical and chemical attributes comprising habitat of wetland ecosystems. It also incorporates a structural index based on a set of species identified for the specific model application. Although models used in a HEP methodology might be more appropriate to a riparian setting in this region, their overall evaluation of potential changes to the ecosystem dynamic are limited when capturing wetland functionality as a whole. The HGM approach has one important advantage over the HEP methodology (HSI models in particular) in that it is more inclusive of all ecosystem functions relevant to ecosystem services. Available HEP models were limited to the habitat function in support of species richness, and might overlook key hydrologic influences experienced in high-flow periods.

1.6 Introduction To The HGM Process

Wetland ecosystems share a number of common attributes including relatively long periods of inundation or saturation, hydrophytic vegetation, and hydric soils. In spite of these common attributes, wetlands occur under a wide range of climatic, geologic, and physiographic situations and exhibit a wide range of physical, chemical, and biological characteristics and processes (Ainslie et al., 1999; Ferren, Fiedler, and Leidy, 1996; Ferren et al., 1996a,b; Mitch and Gosselink, 1993; Semeniuk, 1987; Cowardin et al., 1979). The variability of wetlands makes it challenging to develop assessment methods that are both accurate (i.e., sensitive to significant changes in function) and practical (i.e., can be completed in the relatively short time frame available for conducting assessments). Existing "generic" methods, designed to assess multiple wetland types throughout the United States, are relatively rapid, but lack the resolution necessary to detect significant changes in function. One way to achieve an appropriate level of resolution within the available time frame is to reduce the level of variability exhibited by the wetlands being considered (Smith et al., 1995).

The HydroGeoMorphic Assessment of Wetlands approach (HGM) was developed specifically to accomplish this task (Ainslie et al., 1999; Brinson, 1993). HGM identifies groups of wetlands that function similarly using three criteria (geomorphic setting, water source, and hydrodynamics) that fundamentally influence how wetlands function. "Geomorphic setting" refers to the landform and position of the wetland in the landscape. "Water source" refers to the primary water source in the wetland such as precipitation, overbank floodwater, or groundwater. "Hydrodynamics" refers to the level of energy and the direction that water moves in the wetland. Based on these three criteria, any number of "functional" wetland groups can be identified at different spatial or temporal scales. For example, on a continental scale, Brinson (1993) identified five hydrogeomorphic wetland classes. These were later expanded to the seven classes described in Table 1 (Smith et al., 1995).

Table 1. HydroGeoMorphic Wetland Classes on a Continental Scale

HGM Wetland Class	Definition
Depression	Depression wetlands occur in topographic depressions (i.e., closed elevation contours) that allow the accumulation of surface water. Depression wetlands may have any combination of inlets and outlets or lack them completely. Potential water sources are precipitation, overland flow, streams, or groundwater/interflow from adjacent uplands. The predominant direction of flow is from the higher elevations toward the center of the depression. The predominant hydrodynamics are vertical fluctuations that range from diurnal to seasonal. Depression wetlands may lose water through evapotranspiration, intermittent or perennial outlets, or recharge to groundwater. Prairie potholes, playa lakes, vernal pools, and cypress domes are common examples of depression wetlands.
Tidal Fringe	Tidal fringe wetlands occur along coasts and estuaries, and are under the influence of sea level. They intergraded landward with riverine wetlands where tidal current diminishes, and river flow becomes the dominant water source. Additional water sources may be groundwater discharge and precipitation. The interface between the tidal fringe and riverine classes is where bi-directional flows from tides dominate over unidirectional ones controlled by floodplain slope of riverine wetlands. Because tidal fringe wetlands frequently flood and water table elevations are controlled mainly by sea surface elevation, tidal fringe wetlands seldom dry for significant periods. Tidal fringe wetlands lose water by tidal exchange, by overland flow to tidal creek channels, and by evapotranspiration. Organic matter normally accumulates in higher elevation marsh areas where flooding is less frequent, and the wetlands are isolated from shoreline wave erosion by intervening areas of low marsh. *Spartina alterniflora* salt marshes are a common example of tidal fringe wetlands.
Lacustrine Fringe	Lacustrine fringe wetlands are adjacent to lakes where the water elevation of the lake maintains the water. Fringe table in the wetland. In some cases, these wetlands consist of a floating mat attached to land. Additional sources of water are precipitation and groundwater discharge, the latter dominating where lacustrine fringe wetlands intergrade with uplands or slope wetlands. Surface water flow is bi-directional, usually controlled by water-level fluctuations resulting from wind or seiche. Lacustrine wetlands lose water by flow returning to the lake after flooding and evapotranspiration. Organic matter may accumulate in areas sufficiently protected from shoreline wave erosion. Unimpounded marshes bordering the Great Lakes are an example of lacustrine fringe wetlands.

Table 1. (cont.) HydroGeoMorphic Wetland Classes on a Continental Scale

HGM Wetland Class	Definition
Slope	Slope wetlands are found in association with the discharge of groundwater to the land surface or sites with saturated overland flow with no channel formation. They normally occur on sloping land ranging from slight to steep. The predominant source of water is groundwater or interflow discharging at the land surface.. Precipitation is often a secondary contributing source of water. Hydrodynamics are dominated by down-slope unidirectional water flow. Slope wetlands can occur in nearly flat landscapes if groundwater discharge is a dominant source to the wetland surface. Slope wetlands lose water primarily by saturated subsurface flows, surface flows, and by evapotranspiration. Slope wetlands may develop channels, but the channels serve only to convey water away from the slope wetland. Slope wetlands are distinguished from depression wetlands by the lack of a closed topographic depression and the predominance of the groundwater/interflow water source. Fens are a common example of slope wetlands.
Mineral Soil	Mineral soil flats are most common on interfluves, extensive relic lake bottoms, or large floodplain terraces Flats where the main source of water is precipitation. They receive virtually no groundwater discharge, which distinguishes them from depressions and slopes. Dominant hydrodynamics are vertical fluctuations. Mineral soil flats lose water by evapotranspiration, overland flow, and seepage to underlying groundwater.. They are distinguished from flat upland areas by their poor vertical drainage due to impermeable layers (e.g., hardpans), slow lateral drainage, and low hydraulic gradients. Mineral soil flats that accumulate peat can eventually become organic soil flats. They typically occur in relatively humid climates. Pine flatwoods with hydric soils are an example of mineral soil flat wetlands.
Organic Soil Flats	Organic soil flats, or extensive peat lands, differ from mineral soil flats in part because their elevation and Soil Flats topography are controlled by vertical accretion of organic matter. They occur commonly on flat interfluves, but may also be located where depressions have become filled with peat to form a relatively large flat surface. Water source is dominated by precipitation, while water loss is by overland flow and seepage to underlying groundwater. They occur in relatively humid climates. Raised bogs share many of these characteristics but may be considered a separate class because of their convex upward form and distinct edaphic conditions for plants. Portions of the Everglades and northern Minnesota peat lands are examples of organic soil flat wetlands.

Table 1. (cont.) HydroGeoMorphic Wetland Classes on a Continental Scale

HGM Wetland Class	Definition
Riverine	Riverine wetlands occur in floodplains and riparian corridors in association with stream channels. Dominant water sources are overbank flow from the channel or subsurface hydraulic connections between the stream channel and wetlands. Additional sources may be interflow, overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flows down the floodplain may dominate hydrodynamics. In headwaters, riverine wetlands often intergrade with slope, depressional, poorly drained flat wetlands, or uplands as the channel (bed) and bank disappear. Perennial flow is not required. Riverine wetlands lose surface water via the return of floodwater to the channel after flooding and through surface flow to the channel during rainfall events. They lose subsurface water by discharge to the channel, movement to deeper groundwater (for losing streams), and evapotranspiration. Peat may accumulate in off-channel depressions (oxbows) that have become isolated from riverine processes and subjected to long periods of saturation from groundwater sources. Bottomland hardwoods on floodplains are an example of riverine wetlands.

In many cases, the level of variability in continental-scale wetland hydrogeomorphic classes is still too immense to develop assessment models that can be rapidly applied while being sensitive enough to detect changes in function at a level of resolution appropriate to the planning process. For example, at a continental geographic scale the depression class includes wetlands as diverse as California vernal pools (Zedler, 1987), prairie potholes in North and South Dakota (Kantrud et al., 1989; Hubbard, 1988), playa lakes in the high plains of Texas (Bolen et al., 1989), kettles in New England, and cypress domes in Florida (Kurz and Wagner, 1953; Ewel and Odum, 1984).

To reduce both inter- and intra-regional variability, the three classification criteria (geomorphic setting, water source, and hydrodynamics) are applied at a smaller, regional geographic scale to identify regional wetland subclasses. In many parts of the country, existing wetland classifications can serve as a starting point for identifying these regional subclasses (Stewart and Kantrud, 1971; Golet and Larson, 1974; Wharton et al., 1982; Ferren, Fiedler, and Leidy, 1996; Ferren et al., 1996a,b; Ainslie et al., 1999). In addition to the three primary classification criteria, certain ecosystem or landscape characteristics may also be useful for distinguishing regional subclasses in certain regions. For example, depression subclasses might be based on water source (i.e., groundwater versus surface water) or the degree of connection between the wetland and other surface waters (i.e., the flow of surface water in or out of the depression through defined channels). Tidal fringe subclasses might be based on salinity gradients (Shafer and Yozzo, 1998). Slope subclasses might be based on the degree of slope, landscape position, source of water (i.e., through-flow versus groundwater), or other factors. Riverine subclasses might be based on water source, position in the watershed, stream order, watershed size, channel gradient, or floodplain width. Examples of potential regional subclasses are shown in Table 2 (Smith et al., 1995; Rheinhardt et al., 1997).

Regional Guidebooks include a thorough characterization of the regional wetland subclass in terms of its geomorphic setting, water sources, hydrodynamics, vegetation, soil, and other features that were taken into consideration during the classification process. Classifying wetlands based on how they function, narrows the focus of attention to a specific type or subclass of wetland, the functions that wetlands within the subclass are most likely to perform, and the landscape/ecosystem factors that are most likely to influence how wetlands in the subclass function. This increases the accuracy of the assessment, allows for repeatability, and reduces the time needed to conduct the assessment.

Table 2. Potential Regional Wetland Subclasses in Relation to Geomorphic Setting, Dominant Water Source, and Hydrodynamics

Geomorphic Setting	Dominant Water Source	Dominant Hydrodynamics	Potential Regional Wetland Subclasses	
			Eastern USA	Western USA/Alaska
Depression	Groundwater or interflow	Vertical	Prairie pothole marshes, Carolina Bays	California vernal pools
Fringe (tidal)	Ocean	Bidirectional, horizontal	Chesapeake Bay and Gulf of Mexico tidal marshes	San Francisco Bay marshes
Fringe (lacustrine)	Lake	Bidirectional, horizonal	Great Lakes marshes	Flathead Lake marshes
Slope	Groundwater	Unidirectional, horizontal	Fens	Avalanche chutes
Flat (mineral soil)	Precipitation	Vertical	Wet pine flatwoods	Large playas
Flat (mineral soil)	Precipitation	Vertical	Peat bogs; portions of Everglades	Peatlands over permafrost
Riverine	Overbank flow from channels	Unidirectional, horizonal	Bottomland hardwood forests	Riparian wetlands

Designed to assess wetlands as a whole, the HGM technique focuses on a wetlands' structural components and the processes that link these components within a system (Bormann and Likens, 1969). Structural components of the wetland and the surrounding landscape (e.g., plants, soils, hydrology, and animals) interact with a variety of physical, chemical, and biological processes. Understanding the interactions of the wetlands' structural components and the surrounding landscape features is the basis for assessing wetland functions and the foundation of the HGM Approach. By definition, wetland functions are the normal or characteristic activities that take place in wetland settings. Wetlands perform a wide variety of functions, although not all wetlands perform the same functions, nor do similar wetlands perform the same functions to the same level of performance. The ability to perform a function is influenced by the characteristics of the wetland and the physical, chemical, and biological processes within the wetland. Wetland characteristics and processes influencing one function often also influence the performance of other functions within the same wetland system. Examples of wetland functions evaluated with Functional Capacity Index (FCI) models are found in Table 3.

Table 3. Wetland Functions Measured In HGM And Their Value To The Ecosystem

Functions Related to the Hydrologic Processes	Benefits, Products, and Services Resulting from the Wetland Function
Short-Term Storage of Surface Water: The temporary storage of surface water for short periods.	Onsite: Replenish soil moisture, import/export materials, and provide a conduit for organisms. Offsite: Reduce downstream peak discharge and volume, and help maintain and improve water quality.
Long-Term Storage of Surface Water: The temporary storage of surface water for long periods.	Onsite: Provide habitat and maintain physical and biogeochemical processes. Offsite: Reduce dissolved and particulate loading and volume, and help maintain and improve surface water quality.
Storage of Subsurface Water: The storage of subsurface water.	Onsite: Maintain biogeochemical processes. Offsite: Recharge surficial aquifers, and maintain base flow and seasonal flow in streams.
Moderation of Groundwater Flow or Discharge: the moderation of groundwater flow or groundwater discharge.	Onsite: Maintain habitat. Offsite: Maintain groundwater storage, base flow, seasonal flows, and surface water temperatures.
Dissipation of Energy: The reduction of energy in moving water at the land/water interface.	Onsite: Contribute to nutrient capital of ecosystem. Offsite: Reduced downstream particulate loading helps to maintain or improve surface water quality.
Functions Related to Biogeochemical Processes	**Benefits, Products, and Services Resulting from the Wetland Function**
Cycling of Nutrients: The conversion of elements from one form to another through abiotic and biotic processes.	Onsite: Contributes to nutrient capital of the ecosystem. Offsite: Reduced downstream particulate loading helps to maintain or improve surface water quality.
Removal of Elements and Compounds: The removal of nutrients, contaminants or other elements and compounds on a short-term or long-term basis through physical processes.	Onsite: Contributes to nutrient capital of the ecosystem. Contaminants are removed, or rendered innocuous. Offsite: Reduced downstream loading helps to maintain or improve surface water quality.
Retention of Particulates: The retention of organic and inorganic particulates on a short-term or long-term basis through physical processes.	Onsite: Contributes to nutrient capital of the ecosystem. Offsite: Reduced downstream particulate loading helps to maintain or improve surface water quality.

Export of Organic Carbon: The export of dissolved or particulate organic carbon.	Onsite: Enhances decomposition and mobilization of metals. Offsite: Supports aquatic food webs and downstream biogeochemical processes.
Functions Related to Habitat	**Benefits, Products, and Services Resulting from the Wetland Function**
Maintenance of Plant and Animal Communities: the maintenance of plant and animal community that is characteristic with respect to species composition, abundance, and age structure.	Onsite: Maintain habitat for plants and animals (e.g., endangered species and critical habitats) forest and agriculture products, and aesthetic, recreational, and educational opportunities. Offsite: Maintain corridors between habitat islands and landscape/regional biodiversity.

Wetland functions represent the currency or units of the wetland system for assessment purposes, but the integrity of the system is not disconnected from each function, rather it represents the collective interaction of all wetland functions. Consequently, wetland assessments using the HGM approach require the recognition by both the Assessment Team and the end user that this link (i.e., between wetland function and system integrity) is critical. One cannot develop criteria, or models, to maximize a single function without having potentially negative impacts on the overall ecological integrity and sustainability of the wetland system as a whole. For example, one should not attempt to create a wetland to maximize water storage capacity without the recognition that other functions (e.g., plant species diversity) will likely be altered from those similar wetland types with less managed conditions. This does not mean that a wetland cannot be developed to maximize a particular function, but that it will typically not be a sustainable system without future human intervention.

The HGM approach is characterized and differentiated from other wetland assessment procedures in that it first classifies wetlands based on their ecological characteristics (i.e., landscape setting, water source, and hydrodynamics). Second it uses reference sites to establish the range of wetland functions. Finally, the HGM approach uses a relative index of function (Functional Capacity Index or FCI), calibrated to reference wetlands, to assess wetland functions. In the HGM methodology, a VSI, is a mathematical relationship that reflects a wetland function's sensitivity to a change in a limiting factor or variable within the Partial Wetland Assessment Area or PWAA (a homogenous zone of similar vegetative species, geographic similarities, and physical conditions that make the area unique). Similar to cover types in HEP, PWAAs are defined on the basis of species recognition and dependence, soils types, and topography. In HGM, VSIs are depicted using scatter plots and bar charts (i.e., functional capacity curves). The VSI value (Y axis) ranges on a scale from 0.0 to 1.0, where a VSI = 0.0 represents a variable that is extremely limiting and an VSI = 1.0 represents a variable in abundance (not limiting) for the wetland.

Reference wetlands are wetland sites selected from a reference domain (a defined geographic area), selected to "represent" sites that exhibit a range of variation within a particular wetland type, including sites that have been degraded/disturbed as well as those sites with minimal disturbance (Ainslie et al., 1999). The use of reference wetlands to scale the capacity of wetlands to perform a function is one of the unique features of the HGM approach. Reference provides the standard for comparison in the HGM approach. Unlike other methods which rely on data from published literature or best professional judgment, the HGM approach requires identification of wetlands from the same regional subclass and from the same reference domain, collection of data from those wetlands, and scaling of' wetland variables to those data. Since wetlands exhibit a wide range of variability, reference wetlands should represent the range of conditions within the reference domain. A basic assumption of HGM is that the highest, sustainable functional capacity is achieved in wetland ecosystems and landscapes that have not been subject to long-term anthropogenic disturbance (Smith et al., 1995). It is further assumed that under these conditions the structural components and physical, chemical, and biological processes within the wetland and surrounding landscape reach a dynamic equilibrium necessary to achieve the highest, sustainable functional capacity. Reference standards are derived from these wetlands and used to calibrate variables. However, it is also necessary to recognize that many wetlands occur in less than standard conditions. Therefore, data must be collected from a wide range of conditions in order to scale model variables from 0.0 to 1.0, the range used for each variable subindex. To assist the user, a list of key terms related to the reference wetland concept in the HGM methodology is provided (Table 4).

Table 4. Reference Wetland Terms and Definitions

Term	Definition
Reference domain	The geographic area from which reference wetlands representing the regional wetland subclass are selected
Reference Wetland	A group of wetlands that encompass the known range of variability in the regional wetland subclass resulting from natural processes and disturbance and from human alteration.
Reference standard wetlands	The subset of reference wetlands that perform a representative suite of functions at a level that wetlands is both sustainable and characteristic of the least human altered wetland sites in the least human altered landscapes. By definition, the functional
Reference standard wetlands variable condition	The range of conditions exhibited by model variables in reference standard wetlands. By wetland variable definition, reference standard conditions receive a variable subindex score of 1.0.
Site potential - Mitigation Project Context	The highest level of function possible, given local constraints of disturbance history, land use, (mitigation project or other factors. Site potential may be less than or equal to the levels of function in reference context) standard wetlands of the regio
Project target - Mitigation Project Context	The level of function identified or negotiated for a restoration or creation project.
Project standards - Mitigation Project Context	Project standards Performance criteria and/or specifications used to guide the restoration or creation activities (mitigation context) toward the project target. Project standards should specify reasonable contingency measures if the project target is not

In the HGM approach, an assessment model is a simple representation of a function performed by the wetland ecosystem (Ainslie et al., 1999). It defines the relationship between one or more characteristics or processes of the wetland ecosystem or surrounding landscape and the functional capacity of a wetland ecosystem. Functional capacity is simply the ability of a wetland to perform a function compared to the level of performance in reference standard wetlands. The HGM methodology is based on a series of predictive Functional Capacity Indices (FCIs). An index of the capacity of wetland to perform a function relative to other wetlands from a regional wetland subclass in a reference domain. Functional capacity indices are by definition scaled from 0.0 to 1.0. An index of 1.0 indicates that a wetland performs a function at the highest sustainable functional capacity, the level equivalent to a wetland under reference standard conditions in a reference domain. An index of 0.0 indicates the wetland does not perform the function at a measurable level and will not recover the capacity to perform the function through natural processes. FCI models combine VSIs in a mathematical equation to rate the functional capacity of a wetland on a scale of 0.0 (not functional) to 1.0 (optimum functionality). An HGM subclass model is basically an assimilation of several FCI models combined in a specific fashion to mimic a site's functionality. Users can review and select several FCI models to evaluate the overall site functionality. All FCI models are described using a single FCI formula (refer to the Single Formula Subclass Models section below). Some examples of HGM FCI models include floodwater detention, internal nutrient cycling, organic carbon export, removal and sequestration of elements and compounds, maintenance of characteristic plant communities, and wildlife habitat maintenance.

Reference sites used for model calibration for Arizona Studies included The Nature Conservancy's Hassayampa River Preserve, the Verde River at the confluence with the Salt River, the Santa Cruz River at Tumacocori, the San Pedro River at the San Pedro National Riparian Conservation Area, and Tanque Verde Wash upstream of the Rillito River confluence. These sites were recommended based on the following criteria: 1) they were reasonable sites considering current conditions, 2) they were in a similar regional Riverine subclass to the Santa Cruz River with similar elevation, topography, gradient, and stream order, 3) they represented important aspects of pre-historical conditions, and 4) they were uniform across political boundaries. Model attendees agreed that no truly ideal reference site exists and restoration to the ideal was not achievable due to inability to remove all stressors. The goal in choosing these sites was that the hydrologic, biogeochemical and habitat characteristics be as undisturbed as possible.

HGM model variables represent the characteristics of the wetland ecosystem (and surrounding landscape) that influence the capacity of a wetland ecosystem to perform a function. HGM model variables are ecological quantities that consist of five components (Schneider, 1994). These include: 1) a name, 2) a symbol, 3) a measure of the variable and procedural statement for quantifying or qualifying the measure directly or calculating it from other measurements, 4) a set of values [i.e., numbers, categories, or numerical estimates (Leibowitz and Hyman, 1997)] that are generated by applying the procedural statement, and 5) units on the appropriate measurement scale. Table 5 provides several examples.

Table 5. Components Of A Typical HGM Model Variables

Name (Symbol)	Measure/Procedural Statement	Resulting Values	Units (Scale)
Redoximorphic Features (V_{REDOX})	Status of redoximorphic features/visual inspection of soil profile for redoximorphic features	Present/ Absent	unitless (Nominal Scale)
Floodplain Roughness (V_{ROUGH})	Manning's Roughness Coefficient (n) Observe wetland characteristics to determine adjustment values for roughness component to add to base value	0.01 0.1 0.21	unitless (Interval Scale)
Tree Biomass (V_{TBA})	Tree basal area/measure diameter of trees in sample plots (cm), convert to area (m), and extrapolate to per hectare basis	5 12.8 36	m^2/ha (Ratio Scale)

HGM model variables occur in a variety of states or conditions in reference wetlands (Ainslie et al., 1999). The state or condition of the variable is denoted by the value of the measure of the variable. For example, tree basal area, the measure of the tree biomass variable could be large or small. Similarly, recurrence interval, the measure of overbank flood frequency variable could be frequent or infrequent. Based on its condition (i.e., value of the metric), model variables are assigned a variable subindex. When the condition of a variable is within the range of conditions exhibited by reference standard wetlands, a variable subindex of 1.0 is assigned. As the condition deflects from the reference standard condition (i.e., the range of conditions that the variable occurs in reference standard wetland), the variable subindex is assigned based on the defined relationship between model variable condition and functional capacity. As the condition of a variable deviates from the conditions exhibited in reference standard wetlands, it receives a progressively lower subindex reflecting its decreasing contribution to functional capacity. In some cases, the variable subindex drops to zero. For example, when no trees are present, the subindex for tree basal area is zero. In other cases, the subindex for a variable never drops to zero. For example, regardless of the condition of a site, Manning's Roughness Coefficient (n) will always be greater than zero.

HGM combines both the wetland functionality (FCIs measured with variables) and quantity of a site to generate a measure of change referred to as Functional Capacity Units (FCUs). Once the FCI and PWAA quantities have been determined, the FCU values can be mathematically derived with the following equation: FCU = FCI x Area (measured in acres). Under the HGM methodology, one FCU is equivalent to one optimally functioning wetland acre. Like HEP, HGM can be used to evaluate further conditions and the long-term affects of proposed alternatives by generating FCUs for wetland functions over several target years. In such analyses, future wetland conditions are estimated for both Without Project and With Project conditions. Projected long-term effects of the project are reported in terms of Average Annual Functional Capacity Units (AAFCUs) values. Based on the AAFCU outcomes, alternative designs can be formulated, and trade-off analyses can be simulated, to promote environmental optimization.